TABLE 6–13 Welding Current Range for Flux-Cored Electrodes

Welding Range For E70T-1 with CO_2 Shielding (DCEP)									
		Minimum				Maximum			
Diameter				Wire Feed Speed				Wire Feed Speed	
in.	mm	Amperes	Volts	in./min	mm/min	Amperes	Volts	in./min	mm/min
0.045	1.2	120	21	168	4,267	300	30	625	15,875
$\frac{1}{16}$	1.6	150	24	100	2,540	425	31	400	10,160
$\frac{5}{64}$	2.0	200	26	95	2,413	450	33	270	6,858
$\frac{3}{32}$	2.4	300	26	95	2,413	600	36	255	5,477
$\frac{7}{64}$	2.8	450	30	110	2,794	750	38	237	6,019
$\frac{1}{8}$	3.2	550	32	98	2,489	850	39	175	4,445

Welding Range For E71T-11 Self-Shielding (DCEN)									
		Minimum				Maximum			
Diameter				Wire Feed Speed				Wire Feed Speed	
in.	mm	Amperes	Volts	in/min	mm/min	Amperes	Volts	in./min	mm/min
0.045	1.1	95	13	65	1,651	180	18.5	200	5,080
$\frac{1}{16}$	1.6	100	15	47	1,193	300	22	189	4,800
0.068	1.7	125	17	49	1,245	300	23	184	4,673
$\frac{5}{64}$	2.0	150	18	47	1,193	300	22.5	124	3,149
$\frac{3}{32}$	2.4	200	17	40	1,016	350	22	93	2,410

duty cycle. The electrode wires have a higher rate of utilization, and more economical weld joint details can be employed. This results in lower-cost weldment, which is the goal for weldment fabricators.

6-6 SUBMERGED ARC WELDING

Submerged arc welding (SAW) is an arc welding process that uses an arc or arcs between a bare metal electrode or electrodes and the weld pool. A blanket of granular flux on the workpieces shields the arc and molten metal. The process is used without pressure and with filler metal from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules). This normally applied automatic welding process is shown in Figure 6–51. This process, also known as *under powder welding* or *smothered arc welding*, was developed in the late 1920s and introduced in the early 1930s.

Principles of Operation

The submerged arc welding process shown in Figure 6–52 uses the heat of an arc between a continuously fed electrode and the work. The heat of the arc melts the surface of the base metal and the end of the electrode.

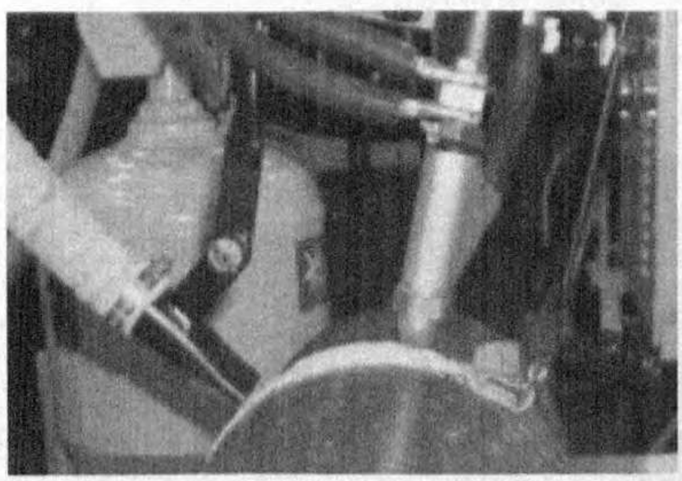


FIGURE 6–51 Submerged arc welding (SAW).

The metal melted off the electrode is transferred through the arc to the workpiece, where it becomes the deposited weld metal. Shielding is obtained from a blanket of granular flux, which is laid directly over the weld area. The flux close to the arc melts and intermixes with the molten weld metal and helps purify and fortify it. The flux forms a glasslike slag that is lighter in weight than the deposited weld metal and floats on the surface

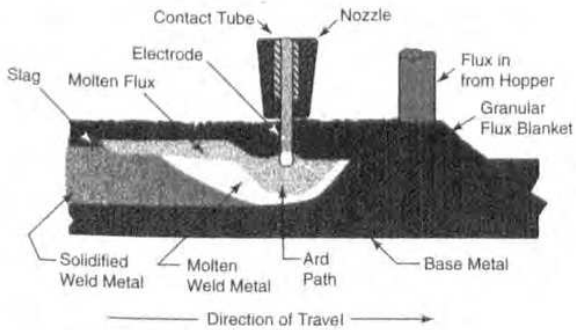


FIGURE 6–52 Process diagram for submerged arc welding (SAW). *Courtesy of* Welding Inspection Technology, *American Welding Society.*

as a protective cover. The weld is submerged under this layer of flux and slag—hence the name *submerged arc welding*.

The flux and slag normally cover the arc so that it is not visible. The unmelted portion of the flux can be reused. The electrode is fed into the arc automatically from a coil. The arc is maintained automatically and travel can be manual or by machine. The arc is initiated by a fuse-type start or by a reversing feed system. The metal transfer mode is less important in submerged arc welding.

Advantages and Major Uses

The submerged arc welding process is one of the older automatic processes and was originally used to make the longitudinal seam in large pipe. It was developed to provide high-quality deposited weld metal by shielding the arc and the molten metal from the contaminating effects of the air. The major advantages of the process are:

- High-quality weld metal
- Extremely high deposition rate and speed
- Smooth, uniform finished weld with no spatter
- Little or no smoke
- No arc flash, thus minimal need for protective clothing
- High utilization of electrode wire
- Easily automated for high operator factor
- Manipulative skills not involved

The submerged arc process is widely used in heavy steel plate fabrication work. This includes the welding of structural shapes and the longitudinal seam of larger diameter pipe, the manufacture of machine components for all types of heavy industry, and the manufacture of vessels and tanks for pressure and storage use. It is widely used in the shipbuilding industry for splicing and fabricating subassemblies, and by many other industries where steels are used in medium to heavy thickness. It is also used for surfacing and buildup work, maintenance, and repair.

Methods of Application and Position Capabilities

The most popular method of applying is the mechanized method where the operator monitors the welding operation. Second in popularity is the automatic method, where welding is a push-button operation. The process can be applied semi-automatically; however, this method of application is not too popular. The process cannot be applied manually because it is impossible for a welder to control an arc that is not visible.

The submerged arc welding process is a limited-position welding process. Welding can be done in the flat position and in the horizontal fillet position with ease. The welding positions are limited because of the large pool of molten metal which is very fluid. The slag is also fluid and will tend to run out of the joint. Under special controlled procedures it is possible to weld in the horizontal position, sometimes called 3-o'clock welding. This requires special devices to hold the flux up so that the molten slag and weld metal cannot run away. The process is not used in the vertical or overhead position.

Weldable Metals and Thickness Range

Submerged arc welding is used to weld low- and medium-carbon steels, low-alloy high-strength steels, quenched and tempered steels, and many stainless steels. Experimentally it has been used to weld certain copper alloys, nickel alloys, and even uranium. Submerged arc welding is also used for hard surfacing and overlay operations.

Metal thickness from 1/16 in. (1.6 mm) to 1/2 in. (13 mm) can be welded with no edge preparation. With edge preparation, welds can be made with a single pass on material from 1/4 in. (6.4 mm) through 1 in. (25 mm). When multi-pass technique is used, the maximum thickness is practically unlimited. Horizontal fillet welds can be made up to 3/8 in. (9.5 mm) in a single pass, and in the flat position fillet welds can be made up to 1 in. (25 mm) size.

Joint Design

The submerged arc welding process can use the same joint design details as the shielded metal arc welding process. These joint details are given in Chapter 19. However, for maximum utilization and efficiency of submerged arc welding, different joint details are suggested.

For groove welds, the square groove design can be used up to a 5/8-in. (16-mm) thickness. Beyond this thickness bevels are required. Open roots are used, but backing bars are necessary because the molten metal will run through the joint. When welding thicker metal, if a sufficiently large root face is used, the backing bar may be eliminated. However, to ensure full penetration when

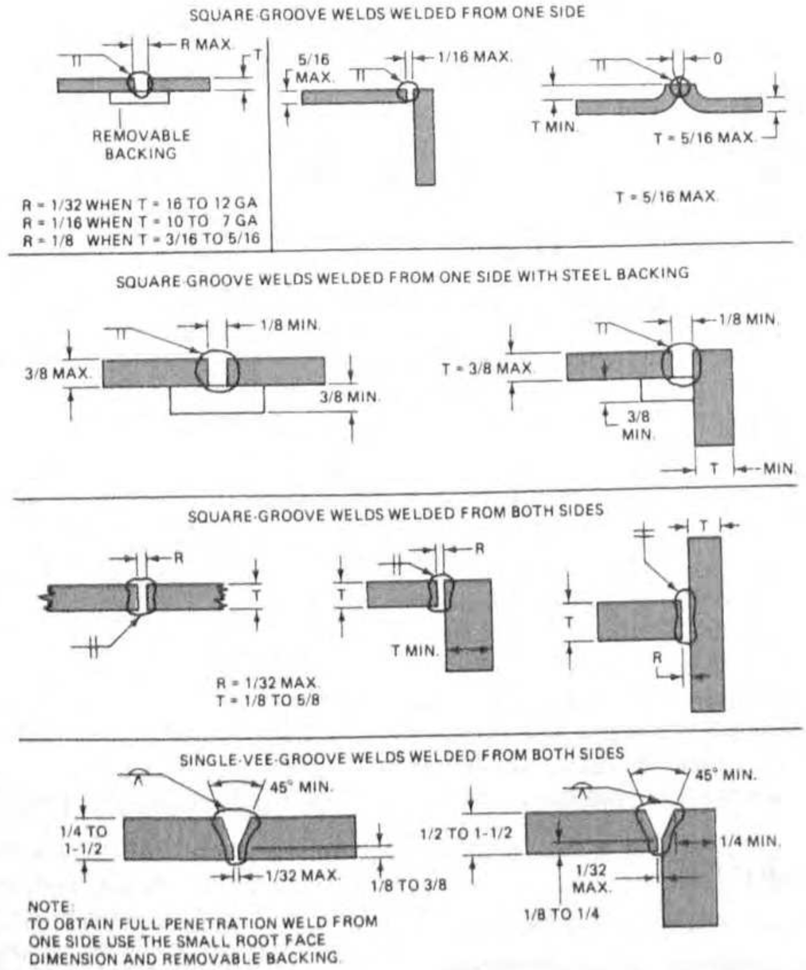


FIGURE 6–53A Weld joint designs for SAW.

welding from one side, backing bars are recommended. Where both sides are accessible, the backing weld can be made, which will fuse into the original weld to provide full penetration. Recommended submerged arc joint designs are shown in Figure 6–53.

Welding Circuit and Current

The welding circuit employed for single-electrode submerged arc welding is shown in Figure 6–52. The submerged arc welding process uses either direct or alternating current for welding power. Direct current is used for most applications that employ a single arc. Both direct-current electrode positive (DCEP) and electrode negative (DCEN) are used, as is alternating current.

The constant-voltage type of DC power is more popular for submerged arc welding with 1/8 in. (3.2 mm) and smaller-diameter electrode wires. The constant-current (CC) power system is normally used for welding with 5/32 in. (4-mm) and large-diameter electrode wires. The control circuit for CC power is more complex since it duplicates the actions of the welder to retain a specific arc length. The wire feed system must sense the voltage across the arc and feed the electrode wire into the arc to maintain this voltage. As conditions change, the wire feed must slow down or speed up to maintain the prefixed voltage across the arc. This adds complexity to the control system, and the system cannot react instantaneously. Arc starting is more complicated with the constant current system since it requires the use of a reversing system to strike the arc, retract, and then maintain the preset arc voltage.

For AC welding the constant-current power is always used. When multiple-electrode-wire systems are used with both AC and DC arcs, the constant-current power system is used. The constant-voltage system, however, can be applied when two wires are fed into the arc supplied by a single power source. Welding current for submerged arc welding can vary from as low as 50 A to as high as 2,000 A. Most submerged arc welding is done in the range 200 to 1,200 A.

Equipment Required

The equipment components required for submerged arc welding (Figure 6–54) consist of (1) welding machine or power source, (2) the wire feeder and control system.

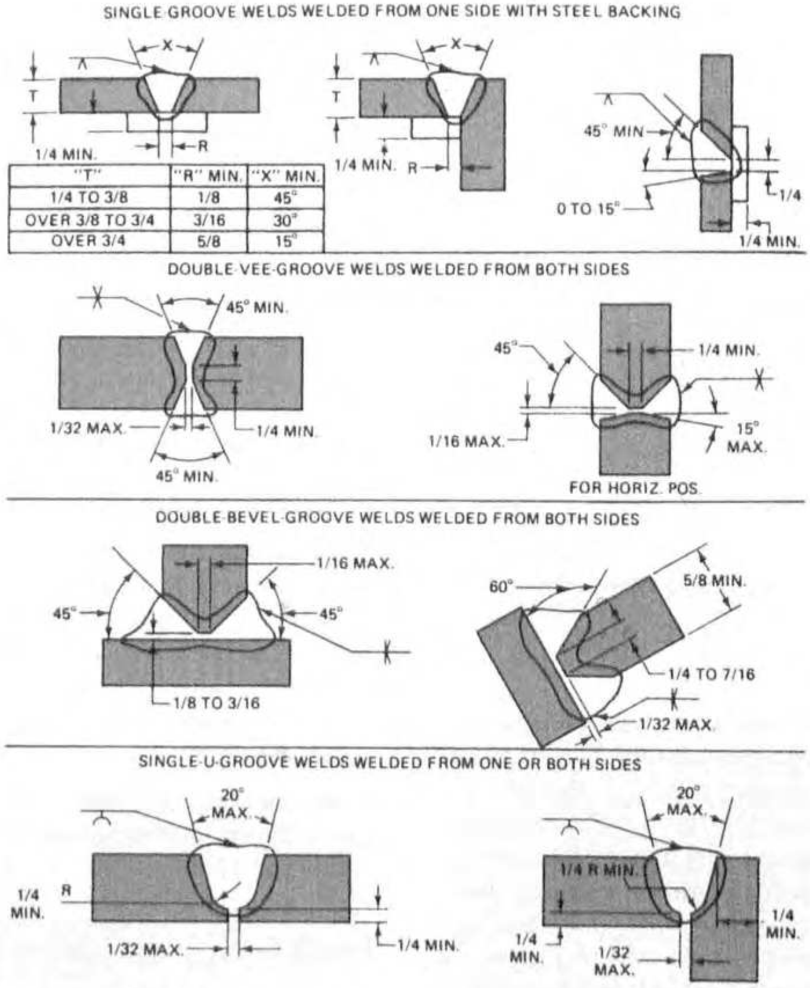


FIGURE 6–53B Weld joint designs for SAW.

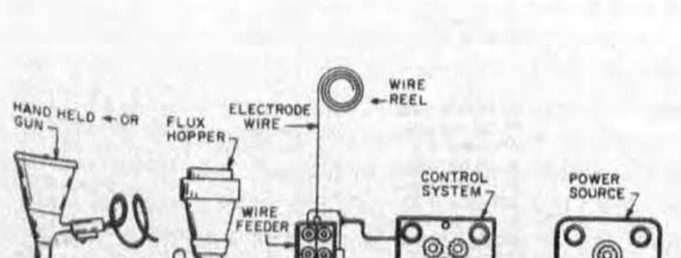


FIGURE 6–54 Circuit diagram for SAW.

(3) the welding torch for automatic welding, or the welding gun and cable assembly for semiautomatic welding, (4) the flux hopper and feeding mechanism and usually a flux recovery system, and (5) travel mechanism for automatic welding.

The power source for submerged arc welding must be rated for a 100% duty cycle, because the submerged arc welding operations are continuous and the length of time for making a weld may exceed 10 minutes. If a 60% duty cycle power source is used, it must be derated according to the duty cycle curve for 100% operation.

When constant current is used, either AC or DC, the voltage-sensing electrode wire feeder system must be used. The CV system is only used with direct current.

Both generator and transformer-rectifier power sources are used, but the rectifier machines are more popular. Welding machines for submerged arc welding range in size from 300 to 1,500 A. They may be connected in parallel to provide extra power for high-current applications. DC power is used for semiautomatic applications, while AC power is used primarily with the mechanized or the automatic method. Multiple-electrode systems require specialized types of circuits, especially when AC is employed.

For semiautomatic application, a welding gun and cable assembly are used to carry the electrode and current and to provide the flux at the arc. A small flux hopper is attached to the end of the cable assembly and the electrode wire is fed through the bottom of this flux hopper through a current pickup tip to the arc. The flux is fed from the hopper to the welding area by means of gravity. The amount of flux fed depends on the height the gun is held above the work. The hopper gun may include a start switch to initiate the weld, or it may use a "hot" electrode so that when the electrode is touched to the work, feeding will begin automatically. Pressure flux feed systems are also used.

For automatic welding, the torch is normally attached to the wire feed motor and the flux hopper is attached to the torch. The flux hopper may have a magnetically operated valve that can be opened or closed by the control system.

The final piece of equipment sometimes used is a travel carriage, which can be a simple tractor or a complex moving specialized fixture. A typical travel carriage is shown in Figure 6-55. A flux recovery unit can be provided to collect the unused submerged arc flux and return it to the supply hopper. Submerged arc welding systems can become more complex by adding such devices as seam followers, weavers, or work movers.

Electrode and Flux

Two materials are used in submerged arc welding, the welding flux and the consumable electrode. The American Welding Society has two specifications[18,19] that provide a classification system for both the flux and the electrode. The flux is specified by the letter *F* followed by a two- or three-digit number that indicates the minimum tensile strength in increments of 10,000 psi. This is followed by a letter that indicates the condition of heat treatment for testing the welds. *A* stands for "as welded," and *P* stands for "postweld heat treated." This is followed by a one- or two-digit number, which indicates the minimum temperature in Fahrenheit of impact tests to provide 20 ft-lb of energy absorption (or the minimum temperature in Celsius of an impact test to provide 27 joules of energy absorption). There are eight classifications for impact strength. The classification for the flux is summarized in Figure 6-56.

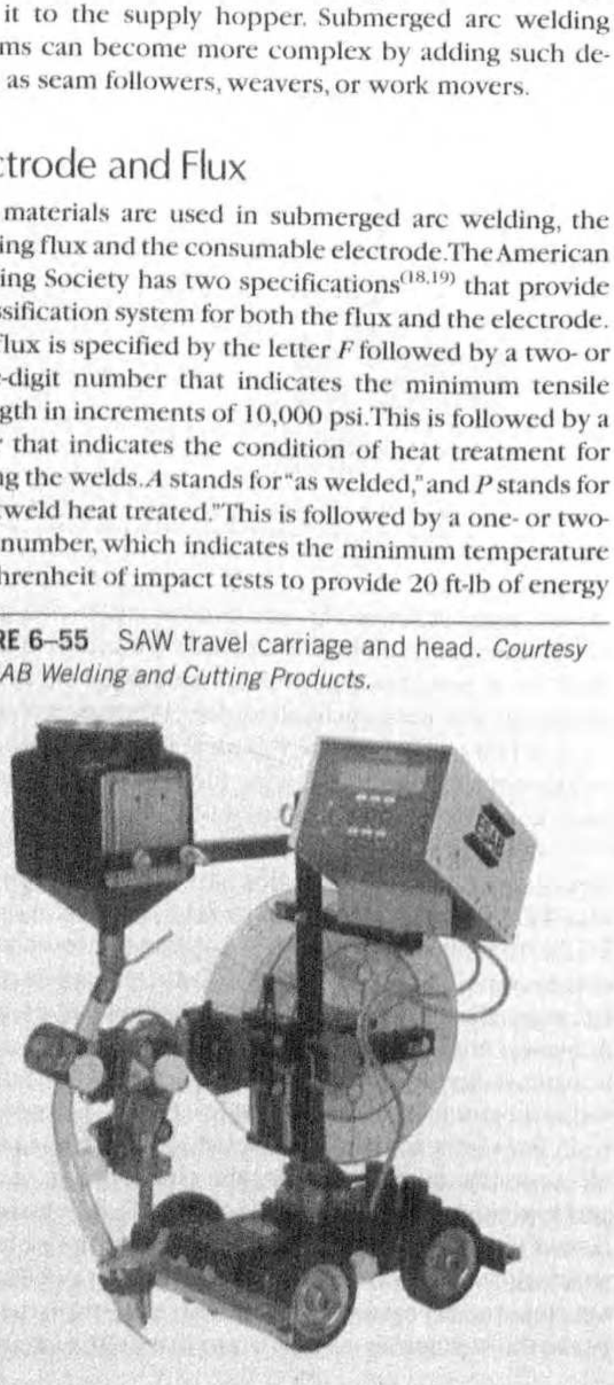


FIGURE 6–55 SAW travel carriage and head. *Courtesy of ESAB Welding and Cutting Products.*

The electrode is specified by the letter *E* followed by three digits. Note, however, that the letter *E* can be followed by the letter *C* if the electrode is of composite construction. Omission of a *C* indicates a solid electrode. The next digit is to designate the manganese content. This is followed by a one- or two-digit number used to indicate nominal carbon content in hundredths of a percent carbon. These digits are sometimes followed by a letter *K*, which indicates that the electrode steel was silicon killed. If the steel is of another type, a *K* will not appear. This is sometimes followed by two digits, which indicate the alloys that are present. Figure 6-57 shows the electrode classification system for carbon steels.[18] This does not, however, cover the alloy steels. For complete information on the alloy steels, refer to the AWS specification.[19] The composition requirements for submerged arc carbon steel electrodes are shown in Table 6-14.

An example of the flux-electrode classification system is as follows:

F7A6-EM12K indicates a flux-electrode combination that will produce weld metal that in the as-welded con-

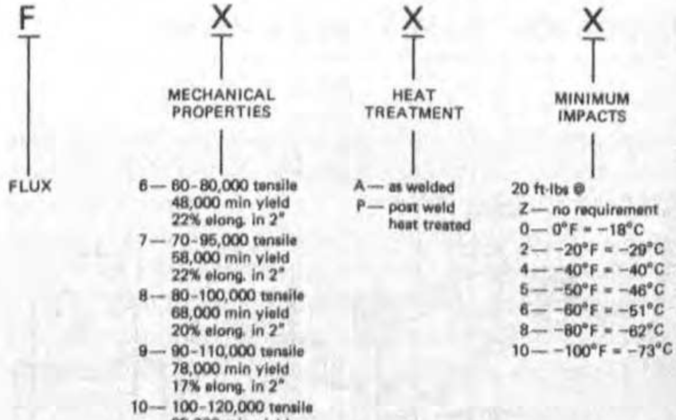


FIGURE 6–56 Classifications for SAW flux.

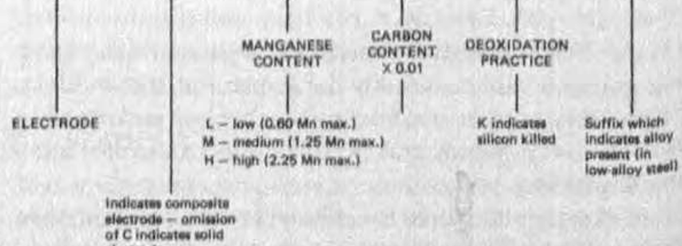


FIGURE 6–57 Classifications for SAW electrode.

TABLE 6–14 Composition Requirements for Submerged ARC Carbon Steel Electrodes

AWS Classification	Chemical Composition (Wt %)[a,b]					
	C	Mn	Si	S	P	Cu[c]
Low-manganese steel electrodes						
ELB	0.10	0.25/0.60	0.07	0.035	0.035	0.35
EL8K	0.10	0.25/0.60	0.10/0.25	0.035	0.035	0.35
EL12	0.05/0.15	0.25/0.60	0.07	0.035	0.035	0.35
Medium-manganese steel electrodes						
EM12	0.06/0/15	0.80/1.25	0.10	0.035	0.035	0.35
EM12K	0.05/0.15	0.80/1.25	0.10/0.35	0.035	0.035	0.35
EM13K	0.07/0.19	0.90/1.40	0.35/0.75	0.035	0.035	0.35
EM15K	0.10/0.20	0.80/1.25	0.10/0.35	0.035	0.035	0.35
High-manganese steel electrodes						
EH14	0.10/0.20	1.70/2.20	0.10	0.035	0.035	0.35

[a]Single values are maximums.

[b]Electrodes are to be analyzed for those elements for which specific values are shown. Elements other than those shown, which are intentionally added (except iron), are also to be reported. The total of these latter elements and all other elements that are not intentionally added must not exceed 0.50%.

[c]The copper limit includes any copper coating that may be applied to the electrode.

dition will have a tensile strength of 20 ft-lb at not less than 70,000 psi and a Charpy V-notch impact strength of at least 20 ft-lbs at −60°F when deposited with an EM12K electrode under standard conditions called for in the AWS Specification.

The flux shields the arc and molten weld metal from atmospheric oxygen and nitrogen. The flux contains deoxidizers and scavengers, which help remove impurities from the weld metal. Flux also provides a means for introducing alloys into the weld metal. Alloys and deoxidizers may also be introduced from the welding electrode.

As the molten flux cools, it forms a glassy slag covering, which protects the surface of the weld. The nonmelted portion of the flux does not change its form; its properties are not affected, so this unmelted flux can be recovered and reused. The flux that melts and forms the slag covering must be removed from the weld. This is easily done after the weld cools and, in many cases, will peel for removal without special effort. In a groove weld the solidified slag may have to be removed by a chipping hammer. The fused flux that is removed must be discarded since the alloying elements and deoxidizers are exhausted during the melting phase.

Selection of Flux Wire Combination

In submerged arc welding it is necessary to select an electrode and flux combination to match the base metal composition and properties. Fluxes of different manufacturers are not interchangeable without making tests. Fluxes may be neutral or active. Neutral fluxes will not produce any significant changes in weld metal chemistry. They are normally used for multi-pass welding. Active fluxes contain small amounts of manganese and/or silicon used to reduce porosity and weld cracking. They are normally used for single-pass applications. The (1) neutral, (2) active, (3) alloy is alloy fluxes, which when used with plain carbon steel electrodes produce alloy weld deposits. This is done to match particular base metals or, with additional alloys, is used for hardfacing applications.

Variations in arc voltage change flux consumption. Higher arc voltage (long arc length) increases the amount of flux melted or consumed. This can cause more alloy to be deposited; hence it is important to follow the manufacturer's recommended voltages when using a particular flux.

In general, the flux is selected based on the mechanical properties required of the weld deposit. The electrode would be selected in conjunction with the flux to deliver these mechanical properties. Manufacturers usually list fluxes with several combinations of electrodes for welding different steels. The manufacturer's recommendations should be followed with respect to single- or multiple-pass type of application related to the base metal properties. If weld requirements are critical, tests should be made to qualify the procedure that will produce the weld properties desired.

Deposition Rates and Quality of Welds

The deposition rates of the submerged arc welding process are higher than any other arc welding process. Four factors control the deposition rate of submerged arc welding: polarity, long stickout, additives in the flux, and additional electrodes. The deposition rate is the highest for direct current electrode negative DCEN. The deposition rate for alternating current is between DCEP and

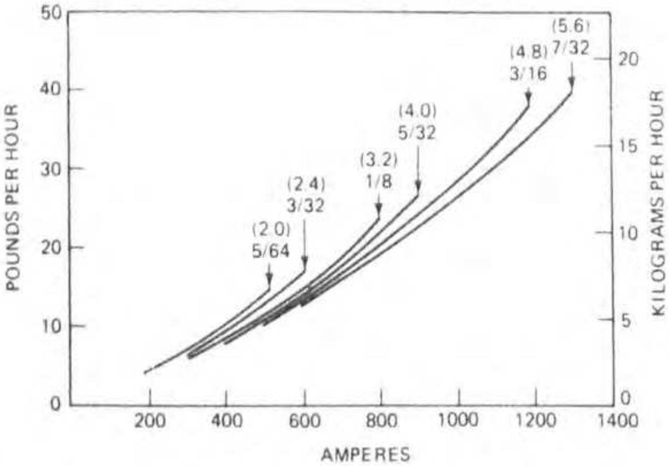


FIGURE 6–58 Deposition rates for SAW.

DCEN. The polarity of maximum heat is the negative pole. Deposition rates for single electrodes are shown in Figure 6–58.

The deposition rate can be increased by extending the stickout. This is the distance from the point where current is introduced into the electrode to the arc. It is also called I^2R welding. Normally, the distance between the contact tip and the work is 1 to 1 1/2 in. (25 to 38 mm). If the stickout is increased, it will cause preheating of the electrode wire, which will greatly increase the deposition rate. As stickout is increased, the penetration into the base metal decreases. This factor must be given serious consideration because in some situations the penetration is required. The relationship between stickout and deposition rate is shown in Figure 6–59. The deposition rates can be increased by metal additives in the submerged arc flux. Additional electrodes can be used to increase the overall deposition rate.

The quality of the weld metal deposited by the submerged arc welding process is high. The weld metal strength and ductility exceeds that of the mild steel or low-alloy base material when the correct combination of electrode wire and submerged arc flux is used. In general, the weld bead size per pass is much greater with submerged arc welding than with any of the other arc welding processes. The heat input is higher and cooling rates are slower, and, for this reason, gases are allowed more time to escape. Uniformity and consistency are advantages of this process when applied automatically.

Several problems may occur when using the semiautomatic application method. The electrode wire may be curved when it leaves the nozzle of the welding gun. This curvature can cause the arc to be struck in a location not expected by the welder. When welding in deep grooves, the curvature may cause the arc to be against one side of the weld joint rather than at the root. This will cause incomplete root fusion, and flux will be trapped at the root of the weld. Another problem with

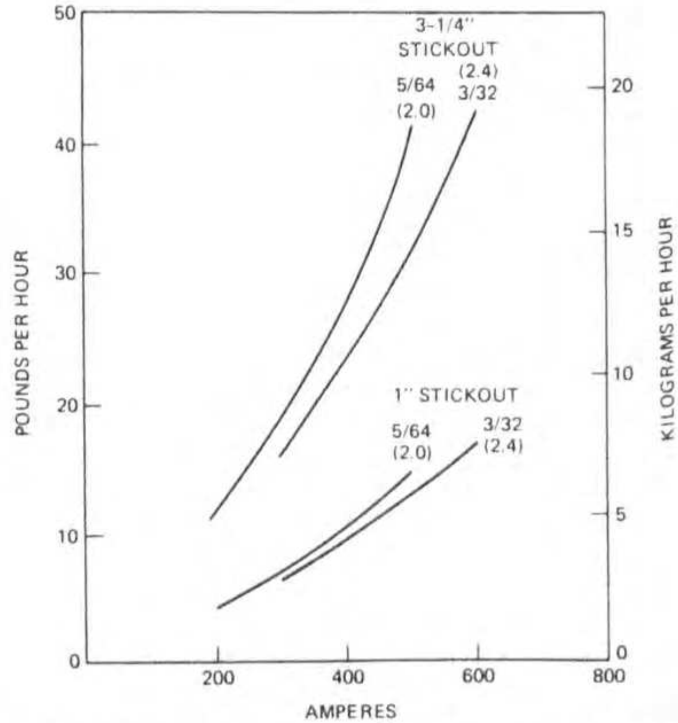


FIGURE 6–59 SMAW versus ASAW deposition rates.

semiautomatic welding is the problem of completely filling the weld groove or maintaining exact size, since the weld is hidden and cannot be observed while it is being made. This requires making an extra pass, or in some cases too much weld is deposited. Variations in root opening affect the travel speed, and if travel speed is uniform, the weld may be under- or overfilled in different areas. High operator skill and experience will overcome this problem.

Another quality problem is associated with extremely large single-pass weld deposits. When these large welds solidify, the impurities in the melted base metal and in the weld metal all collect at the last point to freeze, which is the centerline of the weld. If there is sufficient restraint and enough impurities are collected at this point, centerline cracking may occur. This can happen when making large single-pass flat fillet welds if the base metal plates are 45° from flat. A simple solution is to avoid placing the parts at a true 45° angle. It should be varied approximately 10° so that the root of the joint is not in line with the centerline of the fillet weld. Another solution is to make multiple passes rather than attempting to make a large weld in a single pass.

Excessively hard weld deposits contribute to cracking of the weld during fabrication or during service. A maximum hardness level of 225 Brinell is recommended. The reason for the hard weld in carbon and low-alloy steels is too rapid cooling, inadequate postweld treatment, or excessive alloy pickup in the weld metal. Excessive alloy pickup is due to selecting an electrode that has too much alloy, a flux that introduces too much alloy into the weld, or the use of excessively high welding voltages.

In automatic and mechanized welding, defects may occur at the start or at the end of the weld. The best solution is to use runout tabs so that starts and stops will be on the tabs rather than on the product.

Weld Schedules

The submerged arc welding process applied fully automatically should be done in accordance with welding procedure schedules. Table 6-15 shows some suggested welding schedules using a single electrode on mild and low-alloy steels. These tables can be used for welding other ferrous materials, but were developed for mild steel. All of the welds made by this procedure should pass qualification tests. If the schedules are varied more than 10%, qualification tests should be performed to determine the weld quality.

Welding Variables

The welding variables for submerged arc welding are similar to the other arc welding processes, with several exceptions. The electrode size is related to the weld joint size and the current recommended for the particular joint. This must also be considered in determining the number of passes or beads for a particular joint. Welds for the same joint dimension can be made with many or few passes; this depends on the weld metal metallurgy desired. Multiple passes are more expensive but usually deposit higher-quality weld metal. The polarity is established initially and is based on whether maximum penetration or maximum deposition rate is required.

The major variables that affect the weld involve heat input and include the welding current, arc voltage, and travel speed. Welding current is the most important. For single-pass welds, the current should be sufficient for the desired penetration without burn-through. The higher the current, the deeper the penetration. In multipass work, the current should be suitable to produce the size of the weld expected in each pass.

The arc voltage is varied within narrow limits. It has an influence on the bead width and shape. Higher voltages will cause the bead to be wider and flatter. Extremely high arc voltage can cause cracking. This is because an abnormal amount of flux is melted and excess deoxidizers may be transferred to the weld deposit, lowering its ductility. Higher arc voltage also increases the amount of flux consumed. The low arc voltage produces a stiffer arc that improves penetration, particularly in the bottom of deep grooves. If the voltage is too low, a very narrow bead will result. It will have a high crown, and the slag will be difficult to remove.

Travel speed has an influence on both bead width and on penetration. Faster travel speeds produce narrower beads that have less penetration. This can be an advantage for sheet metal welding, where small beads and minimum penetration are required. If speeds are too fast, however, there is a tendency for undercut and porosity, since the weld freezes quicker. If the travel speed is too slow, the electrode stays in the weld pool too long, which will create poor bead shape and may cause excessive spatter and flash through the layer of flux.

The secondary variables include the angle of the electrode to the work, the angle of the work itself, the thickness of the flux layer, and, most important, the distance between the current pickup tip and the arc, also called *electrode stickout*.

The depth of the flux layer must be controlled. If it is too thin, there will be too much arcing through the flux or arc flash. This also may cause porosity. If the flux depth is too heavy, the weld may be narrow and humped. On the subject of flux, too many fines (small particles of flux) in the flux can cause surface pitting since the gases generated in the weld may not escape. These are sometimes called *pock marks* on the bead surface.

Tips for Using the Process

One of the major applications for submerged arc welding is on circular welds where the parts are rotated under a fixed head. These welds can be made on the inside or outside diameter. Submerged arc welding produces a large molten weld pool and molten slag which tends to run. This dictates that on outside diameters the electrode should be positioned ahead of the extreme top, or 12-o'clock position, so that the weld metal will begin to solidify before it starts the downside slope. This becomes more of a problem as the diameter of the part being welded is smaller. Improper electrode position will increase the possibility of slag entrapment or a poor weld surface. The angle of the electrode should also be changed and pointed in the direction of travel of the rotating part. When the welding is done on the inside circumference, the electrode should be angled so that it is ahead of bottom center, or the 6-o'clock position. Figure 6-60 illustrates these two conditions.

Sometimes the work being welded is sloped downhill or uphill to provide different types of weld bead contours. In Figure 6-61 if the work is sloped downhill, the bead will have less penetration and will be wider. If the weld is sloped uphill, the bead will have deeper penetration and will be narrower. These are based on all other factors remaining the same.

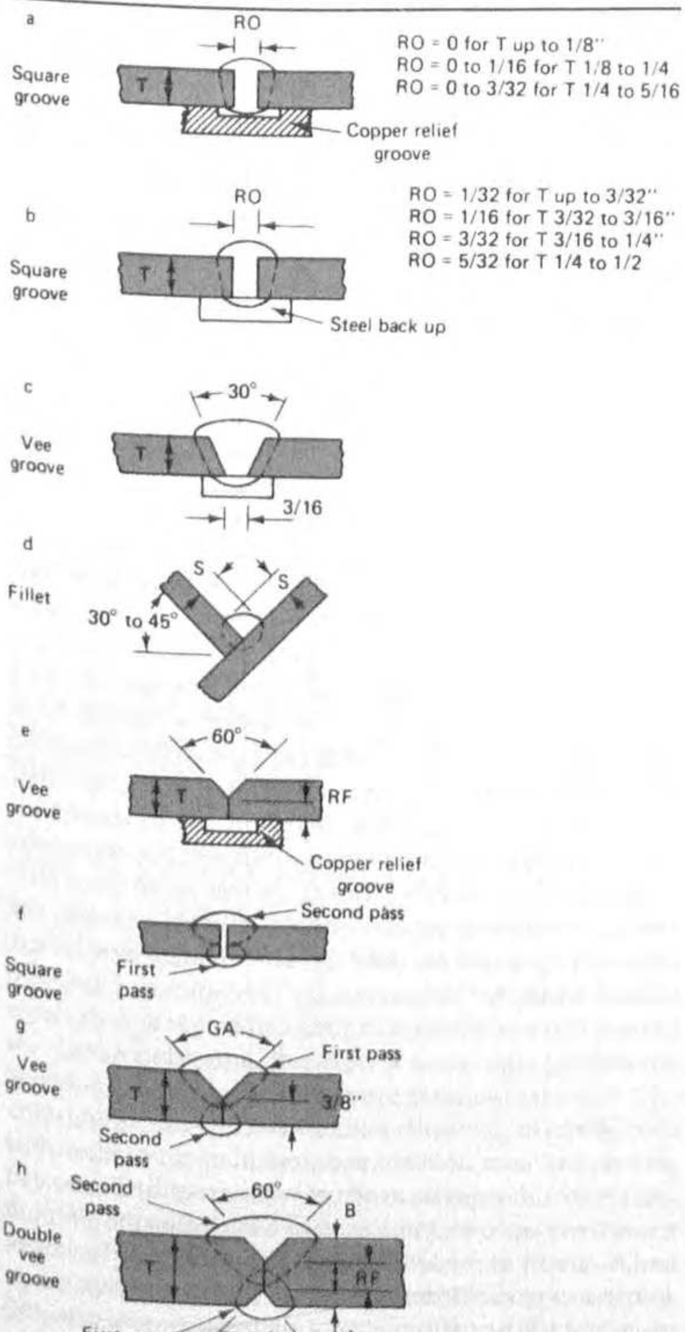
The weld will be different depending on the angle of the electrode with respect to the work when the work is level. This is the travel angle, which can be a drag or push angle, and has a definite effect on the bead

TABLE 6–15 Welding Procedure Schedules for SAW

Material Thickness								
Gauge	in.	mm	Type of Weld	Electrode Dia. (in.)	Arc Welding Current (A DC)	Voltage (Electrode Positive)	Wire Feed (in./min)	Travel Speed (in./min)
18 and thinner			Square groove	1/16	200	20 to 22	85	100–140
16	0.063	1.6	a Square groove	3/32	300	22	68	100–140
			b Square groove	1/8	425	26	53	95–120
14	0.078	2	a Square groove	3/32	375	23	85	100–140
			b Square groove	1/8	500	27	65	75–85
12	0.109	2.8	a Square groove	1/8	400	23	51	70–90
			b Square groove	1/8	550	27	65	50–60
			d Fillet	1/8	400	25	51	40–60
10	0.140	3.5	a Square groove	1/8	425	26	53	50–80
			b Square groove	5/32	650	27	55	40–45
3/16 in.	0.188	4.8	a Square groove	5/32	600	26	50	40–75
			b Square groove	3/16	875	31	55	35–40
			d Fillet	1/8	525	26	67	35–40
1/4 in.	0.250	6.3	a Square groove	3/16	800	28	50	30–35
			b Square groove	3/16	875	31	56	22–25
			d Fillet	5/32	650	28	56	30–35
			e V-groove	3/16	750	30	47	25–40
3/8 in.	0.375	9.5	b Square groove	3/16	950	32	61	20–25
			f Square groove	3/16	First pass 500	32	27	30
					Second pass 750	33	47	30
			e V-groove	3/16	900	33	57	23–25
			d Fillet	3/16	950	31	61	30–35
1/2 in.	0.500	12.6	c V-groove	3/16	975	33	63	12–17
			f Square groove	3/16	First pass 650	34	40	25
					Second pass 850	35	54	23–27
			e V-groove	3/16	950	35	61	18–20
			d Fillet	3/16	950	33	61	14–17
3/4 in.	0.75	19	c V-groove	7/32	1,000	35	49	68
			f Square groove	3/16	First pass 925	37	59	12
					Second pass 1,000	40	65	11
			e V-groove	7/32	950	36	46	10–12
			d Fillet	7/32	1,000	35	49	6–8
			g V-groove	7/32	First pass	34	46	15
					Second pass 750	34	25	22
			h Double V-groove	3/16	First pass 700	35	42	20–22
					Second pass 1,000	36	65	14–16
1 in.	1.000	25.4	g V-groove	7/32	First pass 1,150	36	58	11
					Second pass 850	36	40	20
			h Double V-groove	7/32	First pass 900	36	42	13–15
					Second pass 1,075	36	52	12–14
1 1/4 in.	1.25	32	h Double V-groove	7/32	First pass 1,000	36	50	13
					Second pass 1,125	37	56	8
1 1/2 in.	1.50	38	h Double V-groove	7/32	First pass 1,050	36	51	9
					Second pass 1,125	37	56	7

Note: Wire feed speed is approximate.

TABLE 6–15 *(Continued)*



(b)

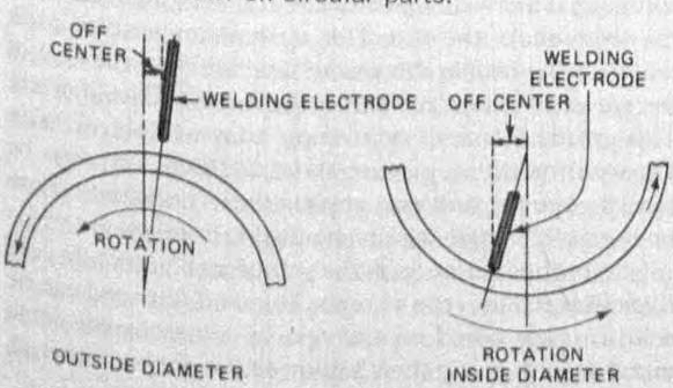


FIGURE 6–60 SAW on circular parts.

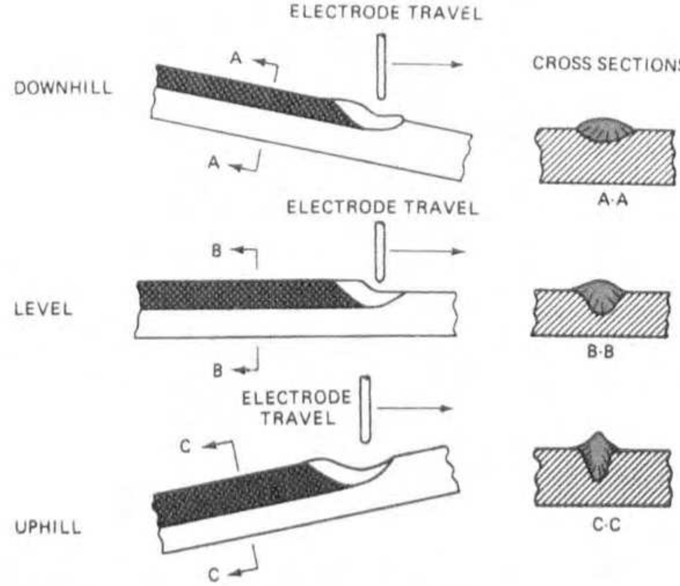


FIGURE 6–61 Angle of slope of work versus weld.

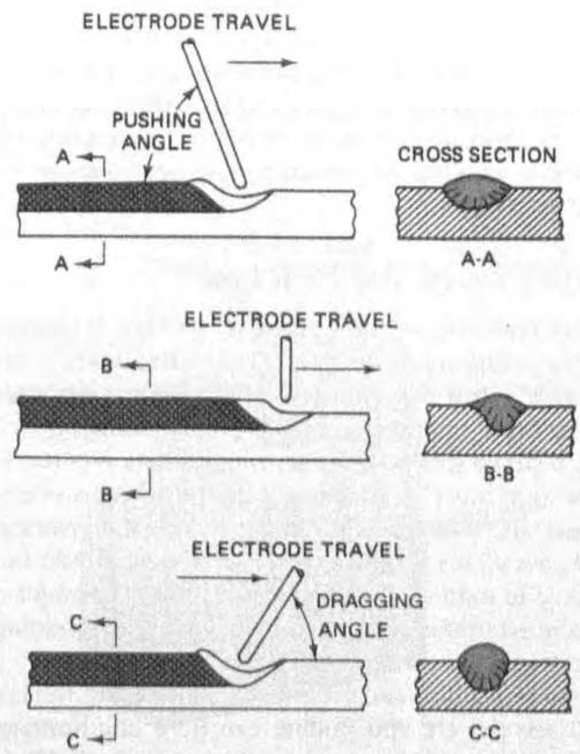


FIGURE 6–62 Angle of electrode versus weld.

contour and weld metal penetration. Figure 6–62 shows the relationship.

One-side welding with complete root penetration can be obtained with submerged arc welding. When the weld joint is designed with a tight root opening and a fairly large root face, high current and electrode positive should be used. If the joint is designed with a root opening and a minimum root face, it will be necessary to use a backing bar since there will be nothing to support the molten weld metal. The molten flux is fluid and will run through narrow openings. If this happens, the weld metal will follow and the weld will burn through the joint. Backing bars are needed whenever there is a root opening and a minimum root face.

Copper backing bars are useful when welding thin steel. Without backing bars, the weld would tend to melt through and the weld metal would fall away from the joint. The backing bar holds the weld metal in place until it solidifies. The copper backing bars may be water cooled to avoid the possibility of melting and copper pickup in the weld metal. For thicker materials, the backing may be submerged arc flux or other specialized type flux. More details of one-side welding are given in Chapter 26.

Safety Considerations

Safety precautions for submerged arc welding are somewhat fewer and less exacting than for other arc welding processes because of the nature of the submerged arc process and because most submerged arc welding is applied automatically. See Chapter 4 for details.

The welding arc is normally not visible in the submerged arc welding process. Only small amounts of sparks or flash are produced; therefore, it is not necessary to wear a welding face helmet. It is necessary to wear tinted safety glasses.

Limitations of the Process

A major limitation of submerged arc welding is its limited welding positions capability. The other limitation is that it is used primarily to weld steels. The high-heat input, slow-cooling cycle can be a problem when welding quenched and tempered steels. The heat input limitation of the steel in question must be strictly adhered to when using submerged arc welding. This may require the making of multi-pass welds where a single pass weld would be acceptable in mild steel. In some cases, the economics may be reduced to the point where flux-cored arc welding or some other process should be considered.

In semiautomatic submerged arc welding, the inability to see the arc and puddle can be a disadvantage in reaching the root of a groove weld and properly filling or sizing.

Variations of the Process

A large number of variations to the submerged arc welding process give it additional capabilities. Some of the more popular variations are:

- Two-wire systems having the same power source
- Two-wire systems having a separate power source
- Three-wire systems having a separate power source
- Strip electrode for surfacing
- Iron powder additions to the flux
- Long stickout welding (mentioned previously)
- Electrically "cold" filler wire

The multiwire systems offer advantages since deposition rates and travel speeds can be improved by using more electrodes. When a single-power source is used, the same drive rolls are used for feeding both electrodes in the weld. When two power sources are used, individual wire feeders must be used to provide electrical insulation between the two electrodes. With two electrodes and separate power, it is possible to use different polarities on the two electrodes or to use alternating current on one and direct current on the other. The electrodes can be placed side by side, in what is called *transverse electrode position*, or they can be placed one in front of the other in the *tandem electrode position*.

The two-wire tandem electrode position with individual power sources is used where extreme penetration is required. The leading electrode is positive, with the trailing electrode negative. The first electrode creates a digging action and the second electrode will fill the weld joint. When two DC arcs are in close proximity, there is a tendency for arc interference between them. In some cases, the second electrode is connected to alternating current to avoid the interaction of the arc. The three-wire tandem system normally uses AC power on all three electrodes connected to three-phase power systems. The three-wire systems are used for making high-speed longitudinal seams for large-diameter pipe and for fabricated beams. Extremely high currents can be used, with correspondingly high travel speeds and deposition rates.

The strip welding system is used to overlay mild and alloy steels, usually with stainless steel. A wide bead is produced that has a uniform and minimum penetration. It is used for overlaying the inside of vessels to provide the corrosion resistance of stainless steel while using the strength and economy of the low-alloy steels for the wall thickness. A strip electrode feeder is required and special flux is normally used. When the width of the strip is over 2 in. (50 mm), a magnetic arc oscillating device is employed to provide for even burn-off of the strip and uniform penetration.

Another way of increasing the deposition rate of submerged arc welding is to add iron base ingredients to the joint under the flux. This is sometimes called *bulk welding*. The iron in this material will melt in the heat of the arc and will become part of the deposited weld metal. This greatly increases deposition rates without decreasing weld metal properties. Metal additives can also be used for special surfacing applications. This variation can be used with single-wire or multiwire installations.

Another variation is the use of an electrically cold filler wire fed into the arc area. The cold filler rod can be solid or flux cored to add special alloys to the weld metal. By regulating the addition of the proper material, the properties of the deposited weld metal can be improved. It is possible to use a flux-cored electrode for one of the multiple electrodes to introduce special alloys into the weld metal deposit. Each of these variations requires special engineering to ensure that the proper material is added to provide the desired deposit properties.

Industrial Use and Typical Applications

The submerged arc welding process is widely used to manufacture most heavy steel products. These include pressure vessels, boilers, tanks, nuclear reactors, chemical vessels, and so on. Another use is in the fabrication of trusses and beams. It is used for welding flanges to the web. The heavy equipment industry is a major user of submerged arc welding. Shipbuilding is another major user of submerged arc welding, using both mechanized and automatic methods. Fully automatic submerged arc machines splice plates together and weld stiffeners to plates. Much of the machine welding is done using welding heads mounted on small carriages. The overlay of surfaces for corrosion resistance and for wear resistance is also a major use for submerged arc welding.

6-7 ELECTROSLAG WELDING

Electroslag welding (ESW) is a welding process that produces coalescence of metals with molten slag that melts the filler metal and the surfaces of the workpieces. The weld pool is shielded by the slag, which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc that heats the slag. The arc is then extinguished by the conductive slag, which is kept molten by its resistance to electric current passing between the electrode and the workpieces. Normally, molding shoes are used to confine the molten weld metal and slag; pressure is not used. This process was invented in the early 1930s in the United States, but became popular when equipment was designed for its use in the Soviet Union in the late 1940s.

Electroslag welding is normally used to make welds in the vertical position and on steels. It is applied as a mechanized welding method. There are two major variations: the consumable guide system, which is shown in Figure 6-63, and the nonconsumable guide system (Figure 6-64), an upward-moving system. The upward-moving system has not been used appreciably in the United States.

In the mid-1970s, electroslag welding became a well-established fabricating process for joining thick components for bridges, buildings, ships, pressure vessels, and more. Electroslag welding was used for splicing flanges, beams, and cover plates of heavy steel girders and rolled beams. However, certain problems began to surface in terms of weld imperfections and insufficient

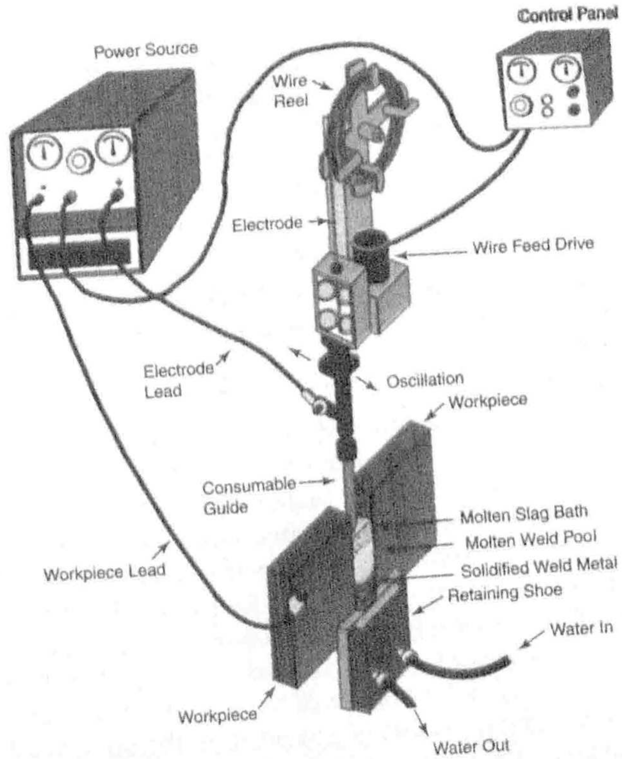


FIGURE 6–63 The ESW consumable guide system. *Courtesy of* Welding Inspection Technology, *American Welding Society.*

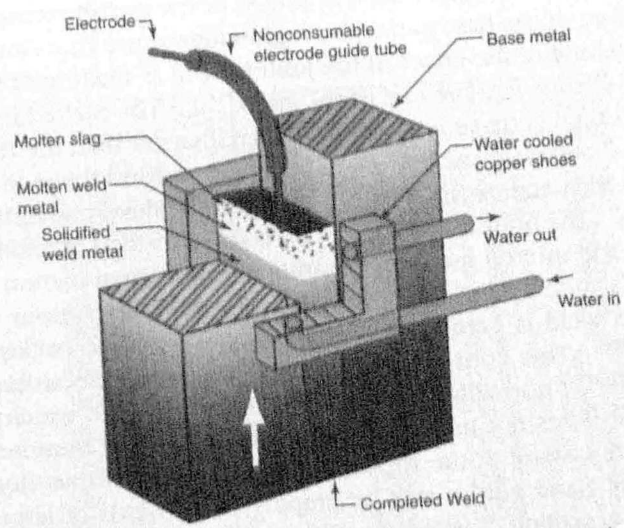


FIGURE 6–64 The ESW nonconsumable guide system. *Courtesy of* Welding Inspection Technology, *American Welding Society.*

properties. During the mid-1970s, research in the field turned up problems of electroslag welded bridge beams. In view of this, the Federal Highway Administration placed a moratorium on the use of electroslag welding (February 1977) for weldments on primary structural tension members on bridges. This led to research at the Oregon Graduate Institute of Science and Technology to improve fracture toughness and fatigue characteristics of the ESW.[20] This research led to modified procedures for consumable guide electroslag welding. An electroslag welding process using the upward-moving head version has been widely used in Europe but not in the United States.

Principles of Operation

Electroslag welding is not an arc welding process. It is included here because it uses the same basic equipment as the other consumable electrode welding processes described in this chapter.

Electroslag welding is done in the vertical position using molding shoes, usually water cooled, in contact with the joint to contain the molten flux and weld metal. The electrode is fed through a guide tube to the bottom of the joint. The guide tube carries the welding current and transmits it to the electrode. The guide tube is normally a heavy wall tube. At the start of the weld, granulated flux is placed in the bottom of the cavity. The electrode is fed to the bottom of the joint and for a brief period will create an arc. In a short time the granulated flux will melt from the heat of the arc and produce a pool of molten flux. The flux is electrically conductive and the welding current will pass from the electrode through the molten flux to the base metal. The passage of current through the conductive flux causes it to become hot, and it reaches a temperature in excess of the melting temperature of the base metal. The high-temperature flux causes melting of the edges of the joint as well as melting of the electrode and the end of the guide tube. The melted base metal, electrode, and guide tube are heavier than the flux and collect at the bottom of the cavity to form the molten weld metal. As the molten weld metal slowly solidifies from the bottom, it joins the parts to be welded. Shielding of the molten metal from atmospheric contamination is provided by the pool of molten flux. Surface contour of the weld is determined by the contour of the backing shoes. The consumable guide variation of electroslag welding normally uses fixed backing shoes. The welding head does not move vertically and is normally mounted on the work at the top of the weld joint. Multiple electrodes and guides may be employed for welds of larger cross section. It is also possible to oscillate the electrode and guide tube across the width of the joint.

The surface of the solidified weld metal is covered with an easily removed thin layer of slag. The slag loss must be compensated for by adding flux during the welding operation. A starting tab is necessary to build up the proper depth of the flux so that the molten pool is formed at the bottom of the joint. Runoff tabs are required at the top of the joint so that the molten flux will rise above the top of the joint. Both starting and runoff tabs are removed from the ends of the joint after the weld is completed.

Advantages and Major Uses

The electroslag welding process is a productive welding process. Some of its advantages are:

- *Extremely high metal deposition rates.* Electroslag has a deposition rate of 35 to 45 lb/hr per electrode.
- *Ability to weld thick materials in one pass.* There is only one setup and no interpass cleaning since there is only one pass.
- *High-quality weld deposit.* Weld metal stays molten longer, allowing gases to escape.
- *Minimized joint preparation and fitup requirements.* Mill edges and square flame-cut edge are normally employed.
- *Mechanized process.* Once started, the process continues to completion. There is little operator fatigue since manipulative skill is not involved.
- *Minimized materials handling.* The equipment may be moved to the work rather than the work moved to the equipment.
- *High filler metal utilization.* All the welding electrode is melted into the joint. In addition, the amount of flux consumed is small.
- *Minimum distortion.* There is no angular distortion in the horizontal plane. There is minimum distortion (shrinkage) in the vertical plane.
- *Minimal time.* It is the fastest welding process for large, thick material.
- *No weld spatter and minimal metal finishing* of the weld.
- *No arc flash.* A welding helmet is not required. Tinted safety glasses are required.

Methods of Application and Position Capabilities

The consumable guide version of electroslag welding is applied as a machine operation. Once the process is started, it should be continued until the weld joint is completed. The welding operator should monitor the apparatus, although little is done in guiding or directing it. Flux is periodically added manually, and the welding operator must monitor the depth of the molten flux pool.

Weldable Metals and Thickness Range

The metals welded by the consumable guide electroslag process are low-carbon steels, low-alloy high-strength steels, medium-carbon steels, and certain stainless steels. Quenched and tempered steels can be electroslag welded; however, a postheat treatment is necessary to compensate for the softened heat-affected zone.

Under normal conditions the minimum-thickness metal welded with the consumable guide method is 3/4 in. (20 mm). Maximum thickness that has been successfully welded with electroslag is 36 in. (950 mm). To weld this thickness, six individual guide tubes and electrodes were used.

A single electrode is used on materials ranging from 1 to 3 in. (25 to 75 mm) thick. From 2 to 5 in. (50 to 125 mm) thick, the electrode and guide tube are oscillated in the joint. From 5 to 12 in. (125 to 320 mm) thick, two electrodes and guide tubes are used and are oscillated in the joint. If oscillation is not employed, additional guide tubes and electrodes are required. This necessitates additional power sources and wire feed systems; therefore, oscillation is preferred where it can be used.

The height of the joint has a definite relationship and must be considered. The process can be used for joints as short as 4 in. (100 mm) and as long or high as 20 ft (6.5 m). It is difficult to oscillate extremely long guide tubes since they become heated and flexible. When two guide tubes are used and properly secured together, it is possible for oscillation; however, as the number of tubes increases, the height of the joint must be decreased. The relationship of joint thickness and joint length or height is shown in Table 6–16.

Joint Design

In electroslag welding, there is just one basic weld, the square-groove weld (Figure 6-65). The square-groove weld can be used to produce butt joints, T-joints, corner joints, and even lap and edge joints. The square-groove butt configuration is used for the transition joint, where two thicknesses of plate are joined with a smooth contour from one thickness to the other. The transition can be in the weld metal. Bead or overlay welds can also be made with electroslag. Examples of different weld joints made with the process are shown in Figure 6-66.

In a square-groove weld, there are only two dimensions: the thickness of the parts being joined, *T*, and the

FIGURE 6–65 Basic joint used in ESW.

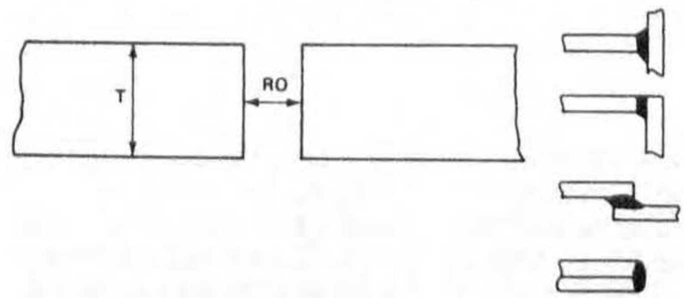


TABLE 6–16 Base Metal Thickness and Height that Can Be Welded Using ESW

Plate Thickness		Root Opening		Joint Height		Number of Electrodes	Oscillation	Welding Voltage (Electrode Positive)	Total Current (A dc)	Vertical Speed	
in.	mm	in.	mm	ft	m					in./min	mm/min
¾	19.0	1	25.4	20	6	1	No	35	500	1.40	36.0
1	25.4	1	25.4	20	6	1	No	38	600	1.20	30.0
2	50.8	1	25.4	20	6	1	No	39	700	1.00	25.0
3	76.2	1	25.4	20	6	1	No	52	700	0.80	20.3
2	50.8	1¼	31.8	5	1.5	1	Yes	39	700	0.76	19.3
3	76.2	1¼	31.8	5	1.5	1	Yes	40	750	0.64	16.3
4	101.6	1¼	31.8	5	1.5	1	Yes	41	750	0.52	13.2
5	127.0	1¼	31.8	5	1.5	1	Yes	46	750	0.40	10.2
3	76.2	1	25.4	20	6	2	No	40	850	0.50	12.7
4	101.6	1	25.4	20	6	2	No	41	850	0.44	11.2
5	127.0	1	25.4	20	6	2	No	46	850	0.38	9.7
5	127.0	1¼	31.8	10	3	2	Yes	41	1,500	0.80	20.3
6	127.0	1¼	31.8	10	3	2	Yes	42	1,500	0.72	18.2
8	203.2	1¼	31.8	10	3	2	Yes	45	1,500	0.54	13.7
10	254.0	1¼	31.8	10	3	2	Yes	48	1,500	0.47	11.9
12	304.8	1¼	31.8	10	3	2	Yes	51	1,500	0.36	9.1
12–18	304.8–457.2	1½	38.1	6	1.8	3	Yes	55	1,800	0.18	4.6
18–24	457.2–609.6	1½	38.1	5	1.5	4	Yes	55	2,400	0.18	4.6
24–30	609.6–762.0	1½	38.1	4	1.2	5	Yes	55	3,000	0.18	4.6
30–3_	762.0–914.4	1½	38.1	3	1	6	Yes	55	3,600	0.18	4.6

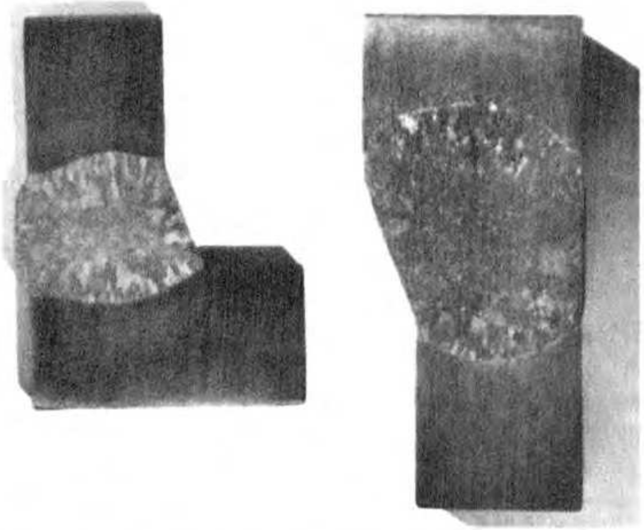


FIGURE 6–66 Examples of joints and welds made with the electroslag process.

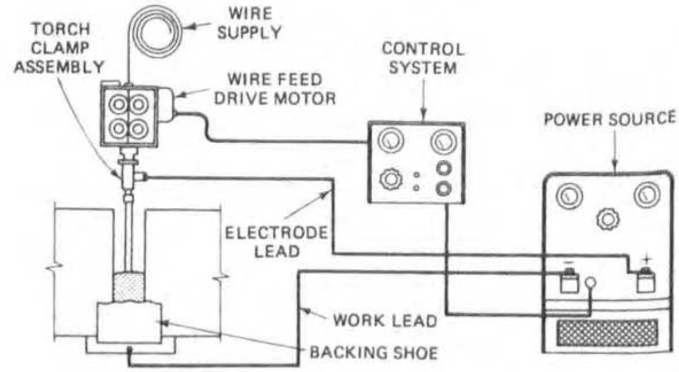


FIGURE 6–67 The welding circuit used in the electroslag process.

root opening between the parts, *RO*. It is desirable to have the root opening as small as possible to use a minimum amount of weld metal. A limiting factor is the size of the consumable guide tube and the insulators that are required to keep it from touching the sides of the joint. The root opening must be large enough to provide sufficient volume of the molten flux to ensure stable welding conditions.

The water-cooled backing shoes are designed to accommodate the different types of joints. Shoes are available for the square-groove welding with reinforcing used for butt joints and for other joints where the surfaces of the plates to be joined are flush. For square-groove welds involving corner or T-joints, fillet-type shoes are used.

Welding Circuit and Current

The welding circuit used is shown in Figure 6–67. For the consumable guide system, DC welding power is employed. The electrode is positive (DCEP). The constant voltage (CV) system with the constant-adjustable-speed wire feeder is used.

In the normal electroslag welding process, alternating current is often used, especially for three-wire systems. In these cases, the constant-feed electrode wire drive motor is used, and the characteristics of the power source are close to flat. The electrical characteristics of the conductive molten flux are similar to those of a high-current welding arc.

Welding current per electrode wire may range from as low as 400 A to as high as 800 A. The weld voltage will range from 25 to 55 V. The high voltage is extremely important, especially when using long guide tubes.

Equipment Required

The equipment required for the consumable guide electroslag welding process is also shown in Figure 6–67. The systems become more complex as additional electrodes are added. The use of oscillation provides greater latitude of the consumable guide method. All the electrode wires are mounted on one oscillating assembly, so only one oscillating device and control are required.

The power source used for the consumable guide electroslag welding process should be a direct-current welding machine of the CV type. It must be rated at a 100% duty cycle since some electroslag welds take hours to complete. The power source should have high voltage ratings since starting voltages as high as 55 V are sometimes required. Transformer–rectifier machines are best suited for electroslag welding. Primary contactors and provisions for remote control, including voltage adjustments, should be included.

When water-cooled backing shoes are used, a system for water circulation and heat removal is required. When running water is available and when it can be easily disposed of, this is the simplest solution. However, water circulating systems, which include heat exchangers, can be used.

Materials Used

Three materials are routinely used in making consumable guide electroslag welds: the flux, electrode wire, and the guide tube. These are specified by the AWS "Specifications for Consumables Used for Electroslag Welding of Carbon and High Strength Low Alloy Steels."(21) Other materials used, including runoff tabs and the starting sump, are reusable and must be the same thickness and composition as the base metal. Insulating material is used for certain applications. Insulators are sometimes required around the bare guide tube to avoid short-circuiting the system if the guide tube comes in contact with the retaining shoes or the face of the weld joint. Other reusable items are the strong backs used to hold the retaining shoes against the weld joint. Wedges are used to hold the retaining shoes in place. The strong backs and wedges are reused many times. When more than one electrode is used, a steel wool ball is placed at the bottom of the joint under the electrode wire to aid arc initiation. Steel wool also can be used for single wire applications, although it is not normally required.

When the work surface is irregular, it is necessary to install a puttylike material to seal the cracks between the shoes and the work. Commercial materials such as furnace sealing compound can be used.

The functions for an electroslag flux are:

1. Providing heat to melt the electrode and base metal
2. Conducting the welding current
3. Protecting the molten weld metal from the atmosphere
4. Purifying or scavenging the deposited weld metal
5. Providing stable operation

Two types of granular fluxes are normally used for electroslag with the consumable guide tube. One is a starting flux, and the other is a running flux. The starting flux is designed to bring the electroslag process into quick stabilization. It melts quickly and wets the bottom of the sump to facilitate starting. The running flux is designed to provide the proper balance for correct electrical conductivity, correct bath temperature and viscosity, and the proper chemical analysis. Running flux will operate over a wide range of conditions. Only a relatively small amount of electroslag flux is used: Approximately 1/4 lb (100 g) of flux is used per vertical foot (320 mm) of the joint or height.

The *electrode* for consumable guide electroslag welding supplies over 80% of the deposited weld metal. The guide tube supplies the remainder. The electrode wire must match the base metal. Since an electroslag weld deposit is similar to a casting, it is essential that the properties of this *as-cast* metal should overmatch the mechanical properties of the parts being joined. It is important to consider the dilution factor provided by the base metal. In a consumable guide weld, the dilution runs from a low of 25% to a high of 50% base metal. The amount of dilution of base metal depends on the welding conditions.

The flux adds no alloys and has little effect on the weld deposit in relationship to the analysis of the wire. Electrode wires designed for gas metal arc welding and submerged arc welding are employed for electroslag welding. The 3/32 in. (2.4 mm) electrode size is the most common. It is the most easily used to feed through a guide tube and produces the highest deposition rate.

The *consumable guide tube* melts just above the surface of the molten slag bath. A guide tube must be used whenever the length of the weld is 6 in. (160 mm) or over, assuming that the head is stationary.

When a bare guide tube is used and if the weld is over 12 in. long (304 mm), insulators should be placed on the tube to avoid the guide tube coming in contact with the sidewall or face of the joint or the retaining shoes. Coated guide tubes are also available and the coating is an effective insulator, particularly when working in tight joints.

There are several variations of the consumable guide tube system. In some cases bars are tack-welded to the guide tube, or tubes are tacked on edges of bars. These bars contribute metal to the weld deposit.

Deposition Rates and Quality of Welds

Deposition rates of the electroslag welding process are among the highest. The electroslag welding process produces a high-quality weld metal deposit. The high quality of electroslag weld metal is the result of progressive solidification, which begins at the bottom of the joint or cavity. There is always molten metal above the solidifying weld metal, and the impurities, which are lighter, rise above the deposited metal and collect only at the very top of the weld in the area that is normally discarded.

Electroslag welding is a low-hydrogen welding process; hydrogen is not present in any of the materials involved in making the weld. Because of the slow cooling rate, any impurities that are in the base metal and are melted during the welding process have time to escape. The cooling rate of the electroslag weld is much slower than the cooling rate of welds made by other arc welding processes. The slow cooling rate allows large grain growth in the weld metal and also in the heat-affected zone of the base metal. The slow cooling rate minimizes the risk of cracking and reduces the hardness in the heat-affected zone sometimes found in conventional arc welds.

Weld metal produced by electroslag welding will qualify under the most strict codes and specifications. The ductility of the weld metal is relatively high, in the range 25% to 30%. The impact requirements for electroslag welds will meet those required by the AWS structural welding code. V-notch Charpy impact specimens producing 5 to 30 ft-lb at 0°F are normal and expected.

Weld Schedules

Welding procedure schedules for electroslag welding with the consumable guide method are provided by the equipment manufacturer. Welding procedure schedules are based on welding low-carbon steel under normal conditions using water-cooled copper shoes and the 5/8 in. (16-mm) outside-diameter guide tube with a 1/8 in. (3.2-mm) inside diameter unless otherwise specified. The electrode diameter is 3/32 in. (2.4 mm), and proprietary starting and running fluxes are used. Oscillation speed is based on the number of seconds per cycle, which is shown as a rate of speed. There is a dwell time at each end of oscillation, which is normally 4 seconds.

Welding Variables

Electroslag welding differs from arc welding processes in that the base metal melting results from localized heat generated in the molten slag pool instead of from an arc. The heating involved in electroslag welding is concentrated in a volume of molten flux, which is the product of the metal thickness by the root opening and by the slag pool depth.

In the arc welding processes, the localized heating is confined to the much smaller area of an arc and pool, but the arc is at a much higher temperature. The operation of electroslag welding is thus different from the familiar arc processes. In electroslag welding the metal surface to be melted (joint sidewalls) is parallel to the axis of the electrode. Thus increasing welding current does not increase the depth of penetration of the sidewalls of the base metal. The higher the welding current, the higher the deposition rate.

With all arc welding processes, an increase in arc voltage causes the weld bead to widen. In electroslag welding, the same thing is true, but now this widening causes an increase in the depth of penetration into the sidewall. The increased voltage raises the slag bath temperature and causes more of the base metal or sidewall to melt. Increasing voltage increases the depth of fusion. Excessively high voltage will cause undercutting. Too low a voltage may result in arcing between electrode wire and the molten weld metal at the bottom of the flux pool. The operator must be continually alert to make adjustments as required during the welding operation. The operator must have a good operating knowledge of electroslag welding because of the different effects of changing the various parameters.

The depth of the molten slag pool should be checked if possible. When the pool is accessible to the operator, a dipstick can be used to determine its depth. Experience will quickly show that when the pool is quiet and the process is running without sparking or sputtering, the pool depth is correct. If the pool depth becomes too shallow, sparks will emit from the surface and can be seen by the operator. Additional flux should be added to the pool.

If the backing shoes leak and water gets into the weld cavity, the operation must be stopped. This can create a safety hazard and will create gross porosity in the weld metal. With respect to water-cooled shoes, the operator must ensure that the water flow is uninterrupted during the entire welding operation.

Safety Considerations

The major safety factor is the presence of a large mass of molten slag and molten weld metal. The high welding current creates a large mass of metal that must be contained within the weld cavity. If the backing shoes should fail and allow the molten metal to escape, it is best to evacuate the area, turn off the equipment, and wait for the metal to solidify. Obviously, the surface under the welding operation should be noncombustible. The work being welded must be securely braced to eliminate the possibility of it falling.

Limitations of the Process

The major limitation is the welding position limitation. It can be used only when the axis of the weld is vertical. A tilt of up to 15° is permitted, but beyond this the process may not function correctly. The second limitation is that the process is used only on steels.

Variations of the Process

Electroslag Cladding This is a variation that deposits surfacing materials on base metals. It is very similar to strip cladding with the submerged arc welding process except that the heat required to melt the surface of the base metal, the strip, and the flux is generated by resistance heating from the current flow to the strip and through a shallow layer of electroconductive slag (Figure 6–68).

Electroslag cladding has become popular because it provides for high deposition rates and low dilution. In addition, it can be used with the same equipment as that used for submerged arc strip cladding. Magnetic oscillation of the arc is recommended for best results. The electroslag process will deposit approximately two times as much metal per hour as the submerged arc method. Dilution is controllable and is usually less than with submerged arc. It will range from 10% to 20%. It is possible to clad ferritic, martensitic, and austenitic stainless steels, nickel-base alloys, and some hard-surfacing materials. Strip width is approximately 2 in. (50 mm) to 2½ in. (61 mm). The major use

FIGURE 6–68 Electroslag cladding.

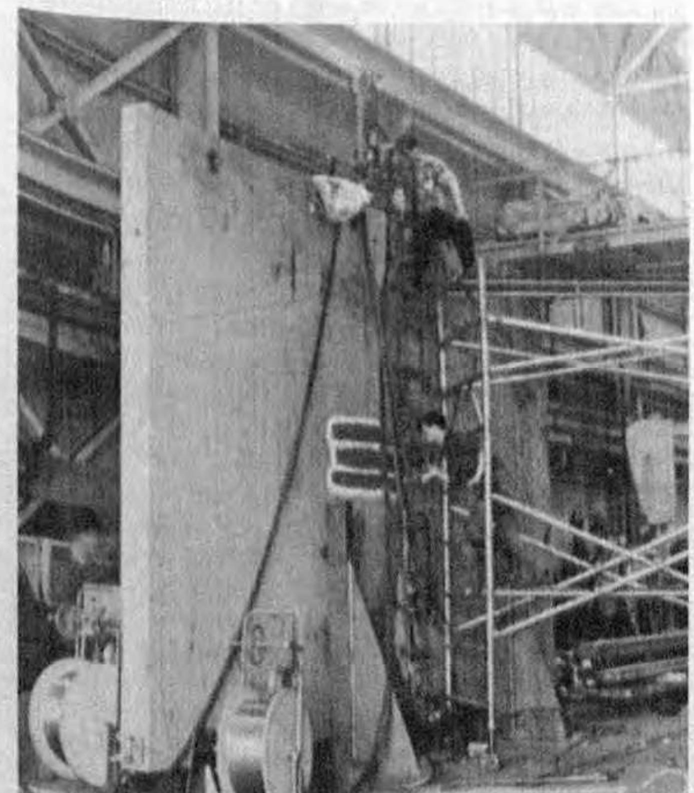
for electroslag cladding is the deposition of austenitic stainless steel on carbon steel for tube sheets and other corrosive-resistant application. Another use is the deposition of corrosion-resistant coatings on large shafts.

Industrial Use and Typical Applications

The major user of conventional consumable guide tube electroslag welding has been the heavy plate fabrication industry, which includes manufacturers of frames, bases, and metalworking machinery. A frequent use of the process is the splicing of rolled steel plates to obtain a larger piece for a specific application. A typical application is the splicing of an 8-in. (203-mm)-thick plate, 12 ft (4 m) wide, to make a press frame (Figure 6–69). The weld joint was set up in the vertical position, strong backs were attached, and the two-wire feeder was placed at the top of the joint. Four water-cooled backing shoes were used, two on either side, which were moved progressively from bottom to top until the weld was completed. Previously, with submerged arc welding and turning the plate over after every few passes, the splicing operation required 80 hours. With the consumable guide electroslag process, the weld was completed in slightly over 4 hours.

Another user of electroslag is the structural steel industry, for making subassemblies for steel buildings. It has also been used for field erection on the building site.

FIGURE 6–69 Using electroslag to join 8 in. thick × 12 ft. wide plates.



A common application is the welding of continuity plates inside box columns. The continuity plate carries the load from one side of the column to the other side at the point of beam-to-column connections. Continuity plates must be welded with complete penetration welds to the two sides of the box column. The electrical machinery industry also uses electroslag welding. Electric motor housings are rolled from a single plate, and a single weld is made to join the two abutting edges. In other cases, the material is heavier or the housing might be square. Electroslag reduces total cycle time because the housing was previously welded with submerged arc one joint at a time.

There are many, many other applications of the consumable guide version, both in the shop and in the field.

6-8 ELECTROGAS WELDING

Electrogas welding (EGW) is an arc welding process that uses an arc between a continuous filler metal electrode and the weld pool, employing vertical position welding with backing to confine the molten weld metal. The process is used with or without an externally supplied shielding gas and without the application of pressure. It is a limited-position arc welding process and is a single-pass process that produces square-groove welds for butt and tee joints.

There are two basic variations: One uses the upward-moving-head variation, the other variation uses the consumable guide tube system described earlier for use with electroslag welding. In addition, both of these variations have two variations. One uses the solid consumable electrode wire and externally supplied shielding gas, normally CO_2. The second uses a flux-cored electrode wire and does not use an external shielding gas since shielding gases are produced by the flux-cored electrode as it is consumed in the arc. Figure 6–70 shows the movable-head variation.

Principles of Operation

The primary difference between electrogas welding and electroslag welding is that the arc is continuous in the electrogas process. Electrogas welding uses an arc between a continuously fed consumable electrode wire and the molten weld pool. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted from the electrode, the metal melted from the surface of the abutting joints, and metal melted from the consumable guide tube, when used, collect at the bottom of the cavity formed between the parts and the molding shoes. This molten weld solidifies from the bottom of the joint and joins the part to be welded. Shielding of the molten metal from the atmosphere is provided by shielding gas from the external source or from the disintegration of the ingredients in the cored electrode wire.

In the moving-head version, the electrode is fed to the bottom of the joint by means of the wire feeder guide

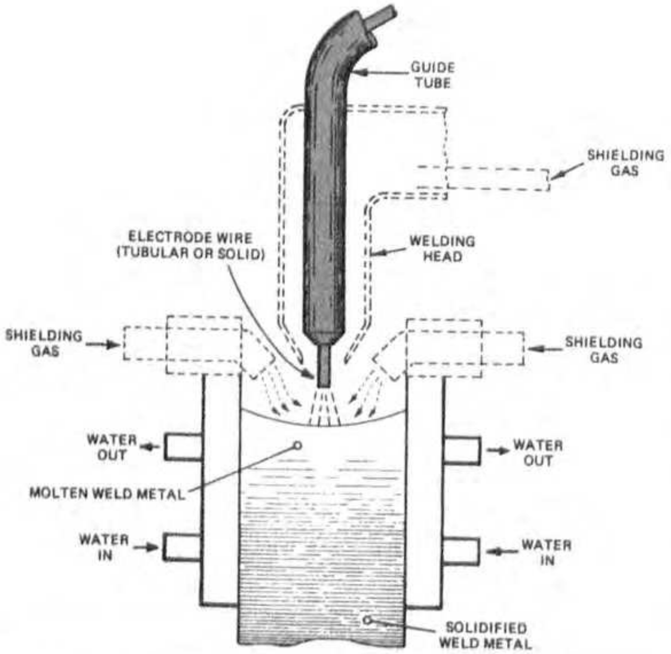


FIGURE 6–70 Process diagram for electrogas welding.

tube or contact tip. This assembly will travel vertically along the joint to maintain the normal arc length between the electrode and the molten weld metal. In some cases one backing shoe is stationary and can be made of steel, thus becoming a part of the joint. Or the molding shoe can be made of copper and does not become a part of the joint, but moves upward. On the side with the wire feeding mechanism, the moving shoe is normally employed, which rises with the wire feeder assembly to maintain the weld metal within the cavity. Normally, only one electrode wire is used for making a weld. In the consumable guide variation, external shielding gas is not used, but the consumable electrode wire must be of the flux-filled type. Both shielding gas and flux are fed into the arc. The flux contained within the electrode wire turns into slag, which covers the weld deposit. Since the correct amount of flux cannot be provided based on the plate thickness and the root opening, a surplus of flux will be generated. The flux must not accumulate and become too deep, which would extinguish the arc. If so, the operation would become an electroslag weld. The excess molten flux leaks through the slots in the water-cooled retaining shoes to avoid flux buildup.

Methods of Application and Position Capabilities

The electrogas welding process is continuous. Once the process has started, it should be continued until the weld joint is completed. The welding operation should be monitored by the operator. The principal purpose is to provide guidance or ensure that the electrode and arc are centered in the joint. It is important to maintain shielding gas flow during the entire welding operation. The arc voltage is used to provide control of the vertical motion of the apparatus. The motion is controlled so that the arc length will remain constant.

The electrogas welding process is a limited position process. It can be used only when the axis of the weld joint is vertical or varies from the vertical by not more than 15°.

Weldable Metals and Thickness Range

The metals welded by the electrogas process are low-carbon steels, low-alloy high-strength steels, medium-carbon steels, and certain stainless steels. The process can also be used for welding quenched and tempered steels providing that the correct heat input is maintained for the type of steel being welded.

Under normal conditions the minimum thickness of metal welded with electrogas is 3/8 in. (10 mm). The maximum thickness using one electrode is 3/4 in. (20 mm). Materials thicker than 3/4 in. are welded by using additional consumable fillers.

The height (or length) of the joint is practically unlimited. The process can be used for joints as short as 4 in. (100 mm) and as long or high as 50 ft (18 m). The only limitation is the weight of the elevating mechanism for moving the weld head vertically.

Joint Design

Fillet welds and groove welds can be produced by the electrogas process. For making fillet welds, a single backing shoe is required. This shoe fits on the face of the fillet and provides the fillet size. For groove welds, the square-groove design can be used up to the maximum possible with one electrode (usually 3/4 in.).

Welding Circuit and Current

The welding circuit used for the electrogas welding process is essentially the same as for the other continuous or consumable electrode processes. The block diagram for electrogas welding is shown in Figure 6–69. Direct-current welding power is employed and the electrode is positive (DCEP). The constant-voltage system with the constant/adjustable speed wire feeder is used. The welding current may range from as low as 100 A to as high as 800 A. The welding voltage will range from 30 to 50 V. The welding voltage is used to control the vertical travel speed of the welding head. The welding head apparatus normally includes the moving shoe required on the electrode side of the weld joint.

Equipment Required

The equipment required for the electrogas welding process is shown in Figure 6–71. The system normally uses one electrode. The welding head assembly is nor-

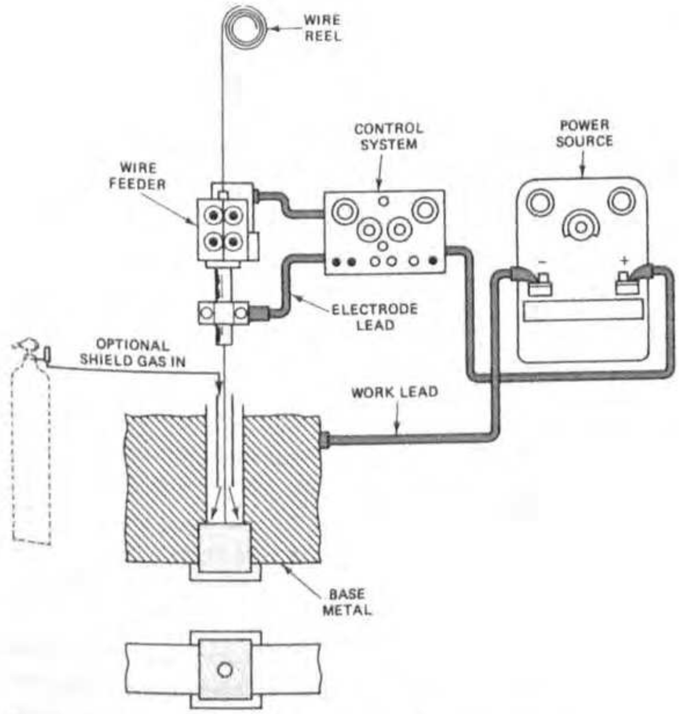


FIGURE 6–71 Circuit diagram for the electrogas welding process.

mally mounted on a carriage, which is elevated as the weld progresses. For shipbuilding, the entire apparatus, which may also carry the welding operator, will move from the bottom of the joint to the top. This is done with a precision elevating system controlled by the welding arc voltage. The control for the entire operation is mounted with the welding head and available to the welding operator. This enables the operator to start the weld and have it run continuously until the joint is completed.

The power source used for electrogas welding should be a direct-current machine of the constant-voltage (CV) type. It must be rated at 100% duty cycle since some electrogas welds take over an hour to complete.

The wire drive feed motor and control system is the same as that used for other consumable electrode wire processes. Normally, the wire feed motor is mounted adjacent to the weld joint, with a contact tube delivery system bringing the electrode into the center of the joint and pointed downward within the cavity.

The shielding gas delivery system, when used, must provide efficient shielding of the molten metal to avoid atmospheric contamination. The moving backing shoes are normally water cooled and designed for the specific joint design. They provide a water flow channel and are made of copper to avoid melting. The water circulation should be of such volume as to avoid any surface melting of the shoes. A water circulator that includes a heat exchanger is normally used. More details concerning electrogas welding are given in the AWS "Recommended Practices for Electrogas Welding."[22]

Electrode Wire

The electrode wire must be matched to the material being welded and can be specified according to the AWS "Specifications for Consumables Used for Electrogas Welding of Carbon Steels and High Strength Low Alloy Steels."[23] This covers the solid wires and the flux-cored wires. The shielding gas, which is normally CO_2, would be specified as welding grade.

Deposition Rates and Quality of Welds

The deposition rate of electrogas welding is relatively high. Flux-cored wire deposition rates vary with wire types and manufacturers since the ratio of fill to metal varies.

Electrogas welding is considered a low-hydrogen type of welding process since hydrogen is not present in any of the materials involved in making a weld. Electrogas welds possess properties and characteristics that surpass welds made with shielded metal arc welding. The higher-than-normal heat input of electrogas welds reduces the cooling rate, which helps reduce impurities. This allows larger grain growth of the weld metal and also in the heat-affected zone of the base metal. This lower cooling rate minimizes the risk of cracking and reduces the high hardness zones in the weld and heat-affected zone sometimes found with shielded metal arc welding. The hardness of the weld is normally uniform across the weld's cross section and is very similar to the unaffected base metal.

Weld metal produced by electrogas welding will qualify under most codes and specifications. The ductility of the weld metal of electrogas weld is relatively high, in the range of 25% elongation. Impact requirements for electrogas welds will meet those required by the AWS Structural Welding Code. V-notch Charpy impact specimens producing 5 to 30 ft-lb at 0°F (19 to 60 joules at 210 to 234°C) are normal and expected.

Weld Schedules

Welding procedure schedules for electrogas welding may not necessarily be the only conditions that can be used. It is possible that welding parameters can be adjusted to obtain optimum results; however, qualification tests should be made before using published welding procedure schedules, especially when welding critical jobs.

Tips for Using the Process

Even though the electrogas process is a machine process, the operator must be continually alert and make adjustments during the welding operation. The operator must have a good operating knowledge of electrogas welding because of the different effect of changing various parameters.

If the electrode wire is not properly centered, the penetration on the opposite sides of the weld joint will be nonuniform. The electrode should be centered between the backing shoes. However, if one shoe is steel rather than copper, the electrode should be directed to the side of the joint with the copper shoe.

If the backing shoe does not fit tightly along the joint, the molten weld metal may run out of the cavity. If this happens, steps must be taken immediately to stop the leak. This is done by using a puttylike sealing preparation made of clay. Any leaks should be immediately sealed off to avoid loss of the weld.

Sufficient wire should be available on the machine prior to starting the weld. Once the weld is started, it should run continuously until it is finished. If the operation stops for any reason, the machine should immediately be turned off, correction made, and the weld restarted. At the point of stopping and restarting, there is normally an unfused area that must be gouged out and rewelded with an arc welding process capable of welding in the vertical position. With respect to water-cooled shoes, the operator must ensure that water flow is uninterrupted during the entire welding operation.

Safety Considerations

The safety factors involved with electrogas welding are much the same as for the other continuous wire arc welding processes. A welding helmet and shield should be worn because the arc is continuous from start to finish. A safety factor involved is the presence of larger-than-normal amounts of molten weld metal. If this metal escapes, it creates a safety hazard and a fire hazard. The work being welded must be securely braced to eliminate the possibility of it falling. In addition, since vertical heights are involved, the equipment should be restrained so as not to fall and personnel should have protective harnesses with safety lines in the event of a fall.

Limitations of the Process

The major limitation is the welding position limitation. The process should not be used if the joint is at an angle in excess of 15° from vertical. The other limitation is that only steel can be welded. For more information, see the AWS "Recommended Practices for Electrogas Welding."[(22)]

Industrial Use and Typical Applications

The major use of electrogas welding has been in the field erection of storage tanks and for splicing. Another user is the shipbuilding industry, for joining shell plates.

6-9 OTHER CONSUMABLE ELECTRODE WELDING PROCESSES

Automatic welding began in the early 1920s, but the covered electrode, which produced higher-quality weld metal, replaced bare electrode automatic welding applications. Automatic welding was improved by using lightly coated wires and later by using knurled wires, which held more of the stabilizing and deoxidizing coating materials. The quality was not as good as that produced by covered electrodes.

Many efforts were made to produce an all-position automatic welding process that would produce high-quality weld metal. The coating on the *covered wire* created two problems. The coating was fragile and brittle and could not be bent into coils without cracking and falling off. The coatings were insulators and the welding current could not be introduced into the metal core wire in an efficient manner. Several developments deserve brief consideration.

One early attempt was made to extrude coatings on large-diameter electrode wire and then coil the wire into extremely large diameter coils. At the welding head a cutter removed the coating from one small area of the wire. The welding current was conducted to the core wire through the slot in the coating by multiple pickup shoes. This process had limited success and has been discontinued.

Another variation, known as the Una-Matic process, used *impregnated tape*. Shielding is obtained from decomposition of an impregnated tape wrapped around the bare electrode as it is fed into the arc. The tape, similar to insect screen wire, was woven in narrow widths, impregnated with stabilizing and deoxidizing chemicals, and coiled. This tape was wrapped around the bare electrode wire below the current pickup jaws and above the arc. This process had limited success and has been discontinued.

Another system used the magnetic field surrounding the electrode wire to carry flux into the arc. The bare electrode wire was fed into the arc, surrounded by carbon dioxide gas that carried powdered magnetic flux. The *magnetic flux* is attracted to the electrode wire by the magnetic field and covered the electrode wire as it entered the arc. The flux performed the normal function. The carbon dioxide gas shielded the molten weld metal from the atmosphere. It never became popular, due largely to the problems of feeding the flux.

Hidden arc welding (HAW) is an automatic arc welding process recently developed by the Moscow Energy Institute in Russia. It uses a square-groove weld design and is usually used in the vertical position. The welding electrode is cut of approximately 1/4 in. thick material the exact size of the joint to be welded. The material is coated with a welding flux, or a flux containing insulation, and is placed on both sides of the electrode. The electrode assembly is clamped between the parts to be welded. The electrode is connected to one pole of the welding machine and the material to the other pole. The arc is initiated at the bottom of the joint by momentarily shorting the electrode to the work. The entire periphery of the joint is encased by copper bars. The arc, once struck, automatically oscillates from one side of the joint to the other and gradually travels from the bottom to the top. No operator assistance or attention is required. When the weld is completed, the arc is extinguished. The copper bars are removed, and the resulting weld is complete. No further work is required. The deposit weld metal is equal to, or exceeds, the quality of the parts being welded. So far, the HAW process has limited applications.

6-10 ARC WELDING VARIABLES

During the manual welding operation, the welder has control over factors that affect the weld. For example, the welder can increase or decrease the speed of travel along the weld joint. The welder can increase the length of the arc, which increases the voltage, or decrease the length of the arc, which decreases the voltage. In this way the welder is also changing the welding current. The welder can also change the angle of the electrode or the torch to either push or drag, and these changes can be made while welding. When all the variables are in proper balance, the welder will have control over the molten metal and will deposit high-quality weld metal. This section will explain how these welding variables interrelate and how some of them are more easily changed and are useful for control.

The effect of changing these variables and the resulting change is essentially the same for all of the arc welding processes when the weld metal crosses the arc. All welds shown are on steel; however, the same factors apply to other metals.

Welding variables can be divided into three classifications: primary adjustable variables, secondary adjustable variables, and preselected or distinct level variables. The *primary* adjustable variables are those most commonly used to change the characteristics of the weld. These are travel speed, arc voltage, and welding current. They can be easily measured and continually adjusted over a wide range. These primary variables control the formation of the weld by influencing the depth of penetration, the bead width, and the bead height (or reinforcement). They also affect deposition rate, arc stability, and spatter level. Specific values are assigned to these variables. They are included in welding procedure schedules and can be duplicated time after time.

The *secondary* adjustable variables can also be changed continuously over a wide range. The secondary adjustable variables do not directly affect bead formation; instead, they cause a change in a primary variable, which in turn causes the change in weld formation. Secondary adjustable variables are more difficult to measure and accurately control. They are assigned values and are usually included in welding procedure schedules. They include tip-to-work distance (stickout) and electrode or nozzle angle.

The third class of variables is known as ***distinct level*** variables, since they cannot be changed in a continuous fashion, but instead normally in increments or in specific steps. Distinct level variables must be preselected and are fixed during a particular weld. They have considerable influence on the weld formation. Distinct level variables that must be preselected are included in welding procedure schedules. They include the electrode size, the electrode type, welding current type and polarity, shielding gas composition, and flux type. These variables are selected with regard to the type and thickness of the material, joint design, welding position, deposition rate, and appearance.

Primary Adjustable Variables

The primary adjustable variables are welding current, arc voltage, and travel speed. To explain the effect of these variables, bead on plate welds is shown with the three characteristics involved: weld penetration, the weld bead width, and the weld reinforcement. Each variable has a distinct effect on the three characteristics.

When making welds to establish a welding procedure or in reviewing welds that did not meet requirements, judgment is based on these three weld characteristics. Weld penetration is the most important, and it is affected by all three of the variables. Penetration is also affected by the secondary adjustable variable and by the preselected variables.

In analyzing the weld if it is decided that penetration must be increased, one of the preselected variables may be changed. For example, if the maximum welding current for a particular electrode size is being used, it would be necessary to change to a larger electrode size to further increase the welding current. This same rationale may have to be followed to change the bead width or weld reinforcement if the limit of a primary variable is reached without obtaining the desired results.

Three sets of curves show the effect of the three primary variables on the three weld characteristics. Figure 6-72 shows the effects of the three variables on weld penetration.

Penetration is the distance that the fusion zone extends below the original surface of the parts being welded. Joint design is also a factor that must be considered. This curve is based on flux-cored arc welding, but would apply to GMAW, submerged arc welding, and, to a fairly large degree, SMAW. The values may change, but the relationships are similar. To explain this, Figure 6-73 shows bead appearance and a cross section of welds made with the FCAW